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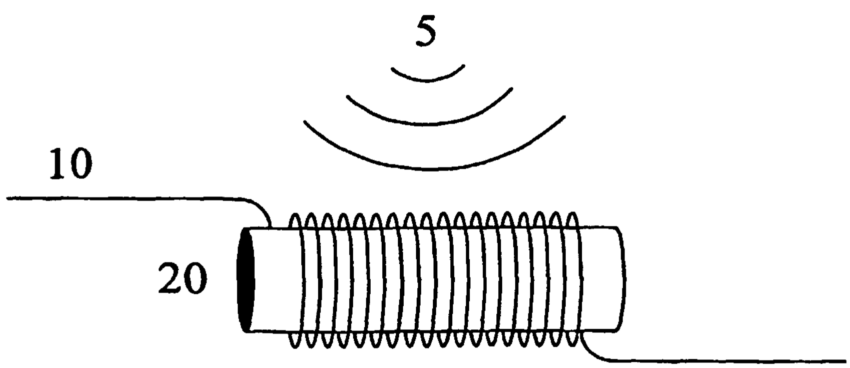
(54) Title: DETECTION OF SOUND WAVES PRODUCED BY A MUSICAL INSTRUMENT



(57) Abstract: Musical instrument sound detection is achieved using a fibre optic acoustic sensor that is sensitive to sound generated by a musical instrument. Sound waves falling on the acoustic sensor cause at least one property of electromagnetic radiation transmitted through the fibre optic to vary. This variation is indicative of the sound generated by the musical instrument and can be detected by an electromagnetic radiation detector.

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DETECTION OF SOUND WAVES PRODUCED BY A MUSICAL INSTRUMENT

The present invention relates to the field of musical instrument sound detection.

High quality sound detection and reproduction of sound generated by musical instruments, and in particular, a stringed musical instrument is notoriously difficult to achieve. One solution, developed for use with the guitar involves the use of magnetic pick-ups to convert vibrations of the string(s) into an electrical signal. Although successful this approach is fundamentally limited as the close proximity of the magnetic pick-ups has a detrimental effect upon the natural string vibrations (and hence tonal quality) of the sound.

A further problem with such systems and in fact with electrical sound detection devices in general is that they are subject to electromagnetic interference from objects in the vicinity, such as fluorescent strip lights, computer monitors etc. This becomes a serious issue in a recording studio environment where background noise needs to be reduced as much as possible.

Piezoelectric sound detection devices have been developed for use with instruments having soundboards. These devices can be glued to a musical instrument that has a soundboard and the vibrations of the soundboard are detected. A drawback of such a system is that the piezoelectric element is generally glued to a single position on the soundboard and, as such, the tonal characteristics of the musical instrument are not fully captured. Given the complex nature of acoustic soundboard resonance (see Figure 1), it would be necessary to affix several piezoelectric devices in order to improve the quality of sound captured from vibrations of the soundboard alone. One problem with this is that owing to their relative lack of sensitivity piezoelectric devices require a reasonable contact surface area, this limits the number of devices that can be used and also affects the sound generated by the soundboard. Furthermore, the signals they produce are susceptible to electromagnetic interference which can be a problem particularly in environments such as recording studios which may have such things as monitor screens and strip lighting.

It would be desirable to provide an improved sound detection device.

A first aspect of the present invention provides a musical instrument sound detection system comprising: a fibre optic acoustic sensor; a source of electromagnetic radiation optically coupled to said fibre optic acoustic sensor and operable to input electromagnetic radiation to said fibre optic acoustic sensor; and an electromagnetic radiation detector arranged to receive electromagnetic radiation output from said fibre optic acoustic sensor and operable to detect at least one property of said output electromagnetic radiation; wherein said fibre optic acoustic sensor is responsive to sound generated by a musical instrument and is operable to vary said at least one property of said input electromagnetic radiation in response to that sound in order to generate the output electromagnetic radiation, said electromagnetic radiation detector being operable to detect variations in said at least one property of said output electromagnetic radiation indicative of this sound generated by the musical instrument and to produce output signals in response thereto.

Fibre optic acoustic sensors have been developed as hydrophones for detecting sound in an underwater environment. They have been adapted for this use by the military as an alternative to existing sonar technology; a significant advantage being that the detected signals are sent as electromagnetic radiation along an optical fibre and as such electrical components do not need to be deployed in the underwater environment. The inventors of the present invention have realised that such devices can be adapted for use with musical instruments to provide improved sound detection. Optical fibre acoustic sensors are small and light and as such, even if attached to a musical instrument, they will only have a very small influence on the sounds produced by the musical instrument that they are detecting. Furthermore, the sensors themselves are immune to background electromagnetic radiation. Positioning the detector at some distance from the musical instrument, possibly even in a shielded environment will reduce electromagnetic interference with the electronics associated with the signal detector, the signal transmitted as electromagnetic radiation is immune to electromagnetic interference. Thus, the problems due to background noise from electrical equipment such as overhead strip lights, or monitors can be alleviated. A further advantage of the optical acoustic sensors pertains to the effective "in-air" range of the device. The fibre optic acoustic sensors have a short in-air acoustic range of around 5cm which is ideal for isolating one musical instrument from a neighbouring

one, when several instruments are being detected together, for example, in a recording studio or during a live recording of several instruments.

In some embodiments, said fibre optic acoustic sensor comprises a fibre laser acoustic sensor, comprising an optical fibre doped to provide a doped lasing volume, said fibre having two gratings provided in said doped volume, said fibre laser acoustic sensor being operable to vary a wavelength of said electromagnetic radiation in response to the sound from the musical instrument, and said input electromagnetic radiation detector being operable to detect variations in wavelength of said output electromagnetic radiation.

Fibre laser devices have the advantage of being very small devices, generally being written into a length of doped optical fibre that is about 5cm long, with a diameter equal to that of the optical fibre.

Preferably, said optical fibre is coated with polyurethane. The polyurethane is caused to vibrate by the acoustic waves and as such serves to increase the sensitivity of the fibre optic acoustic sensor to acoustic waves.

In other embodiments, said fibre optic acoustic sensor comprises an interferometric detector comprising an optical fibre, a portion of said optical fibre being coiled around a compliant core, said sensor further comprising reflectors in optical communication with said optical fibre before and after said coil, such that a portion of said electromagnetic radiation is reflected before entering said coil by a first of said reflectors and a further portion of said electromagnetic radiation is reflected after passing through said coil by a second of said reflectors, said electromagnetic radiation detector being operable to detect variations in phase between said output electromagnetic radiation reflected by each of said reflectors.

Interferometric devices are typically wound around a mandrel having a diameter of about 2.5cm. The main advantage of the interferometric devices are their low cost consisting as they do of standard optical fibre wound around a mandrel.

Preferably, said fibre optic acoustic sensor comprises attachment means for attachment to a musical instrument. The provision of attachment means on the sensor itself makes the device particularly easy to use.

In some embodiments, said musical instrument is a stringed musical instrument.

The device of embodiments of the present invention is particularly well adapted to detect the sound from stringed musical instruments. In particular, the detection device does not interfere with the movement of the strings, which is not the case with magnetic pick-up detection devices. Furthermore, there is no constraint on the type of strings that can be used with these sound detection devices, thus, nylon as well as metal strings can be used.

With stringed devices the attachment means are for attachment across the sound hole, to the bridge, body, acoustic chamber or the soundboard of said stringed musical instrument.

These devices are particularly suitable for attachment to the soundboard as in addition to being light and not affecting the soundboard movement very much they are also sensitive to a larger area than similar piezo-electric devices

Characteristics of the sounds produced by stringed instruments are provided by string vibrations and subsequent vibrations of the soundboard and air within the acoustic chamber; the design of the acoustic chamber and the soundboard being critical in acoustic instruments. The positioning of the fibre optic acoustic sensor(s) affects the tonal quality of the sound that is received. Thus the position of the sensor relative to the bridge and fingerboard will provide control of the sound received. The ability to place a plurality of small sensors in different places means that the quality of sound that can be recorded is very high. In addition to the places listed above, the sensors could also be placed within the soundboard, or between the soundboard and the strings, by the use of appropriate attachment means.

In some embodiments, said system comprises a plurality of fibre optic acoustic sensors, said plurality of fibre optic sensors being arranged in series such that electromagnetic radiation from said source passes through each of said sensors in turn.

Although the sensors may be placed in parallel, placing them in series is a convenient way of connecting the acoustic sensors. Readings from individual sensors can be monitored and processed by the use of pulses and time division multiplexing.

In some embodiments said plurality of fibre optic acoustic sensors are arranged in series along an optical fibre, the distance between respective sensors being such that individual fibre optic sensors may be arranged on different musical instruments with optical fibre connecting said plurality of sensors.

This allows a plurality of different instruments to be recorded and the real time sounds recorded from each to be processed simultaneously by a central processing system.

Preferably, said musical instrument sound detection system further comprises a signal processor operable to process said output signals received from said electromagnetic radiation detector and to produce acoustic signals that are compatible with a conventional amplifier and/or sound recording system therefrom.

By using the sound detection system in conjunction with a signal processor, it can be used not only to detect sound received but in conjunction with conventional kit, such as amplifiers and/or recording equipment to reproduce it too. Given the sensitivity of the sound detection system a very high quality sound can be reproduced.

A further aspect of the present invention provides a musical instrument having a musical instrument sound detection system according to the first aspect of the present invention.

In some embodiments said musical instrument is a solid bodied guitar.

The present invention is particularly suitable for detecting the sound produced by a solid bodied or electric guitar. Generally an electric guitar requires magnetic pick-ups that detect the movement of metal strings and produce sounds related to that movement. One problem with the system is that the monitoring of the metal strings by the magnetic pick-ups effects their movement and thus, the tonal quality and sustain of the sound produced. The use of fibre acoustic sensors alleviates this problem improving the sound quality produced and also allowing other types of strings, such as nylon strings to be used.

A further aspect of the present invention provides a method of detecting sound from at least one musical instrument comprising the steps of:

(i) arranging a fibre optic acoustic sensor to receive sound generated by a musical instrument;

(ii) inputting electromagnetic radiation into said fibre optic acoustic sensor, said fibre optic acoustic sensor being operable to vary at least one property of said input electromagnetic radiation in response to that sound in order to generate output electromagnetic radiation;

(iii) detecting variations in said at least one property of said output electromagnetic indicative of the sound generated by the musical instrument and producing output signals in response thereto.

A still further aspect of the present invention provides the use of a fibre optic acoustic sensor within a musical instrument sound detection system according to the first aspect of the present invention, to detect sound generated by a musical instrument.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows accoustic vibrations on a soundboard of a stringed instrument (from "Acoustics of Violins" by G.M. Hutchins, revised for Sceintific American article, Oct 1981, photo by Dr Raul A stetson);

Figure 2A shows an interferometric fibre optic acoustic sensor;

Figure 2B shows a musical instrument sound detection system according to an embodiment of the present invention comprising interferometric acoustic sensors as shown in Figure 2A;

Figure 3A shows two types of fibre laser acoustic sensor;

Figure 3B shows a musical instrument sound detection system according to an embodiment of the present invention comprising fibre laser acoustic sensors as shown in Figure 3A;

Figure 4 schematically shows a cross section of a stringed instrument with an acoustic sensor attached thereto.

Figure 2A shows an interferometric fibre optic acoustic sensor for use in embodiments of the present invention. This fibre optic acoustic sensor comprises an optical fibre 10 wound around a flexible mandrel 20. Figure 2B shows a plurality of these sensors connected in series and including a laser pump 40 and detector 50. The acoustic sensors comprises reflecting section 30 at either en of the fibre coil. The reflecting section being operable to reflect a portion of the electromagnetic radiation prior to the fibre coil and a further portion after the coil. A laser pump 40 generates pulses of electromagnetic radiation of different frequencies at a predetermined time from each other. A first pulse of frequency f1 is transmitted and then at a certain time later a second pulse of a different but close frequency f2 is transmitted. The time difference between the two pulses being transmitted is set to be the time taken for the

electromagnetic radiation to travel through one coil, so that the second pulse of radiation at f2 enters the coil as the first pulse is reflected by the reflecting portion 30 at the end of the coil. Thus, these two radiation pulses interact and it is this interacting pulse that is measured. This occurs in each coil, with reflecting portions before and after each coil, reflecting a portion of the transmitted light. As the coils are all of the same length then the pulse of frequency f1 is always reflected from one end of a coil just as the pulse of f2 enters the other end. Acoustic waves 5 generated, for example, by a musical instrument, falling on the accoustic sensor cause slight distortions in the flexible mandrel causing changes in the length of the optical fibre 10 and the stress and flexion also cause slight changes in the refractive index of the optical fibre. These changes lead to a change in the phase of the electromagnetic radiation passing through and output from the optical fibre 10, and thus changes in the interactions between the two pulses. The detector 40 detects any pulse differences in these interacting signals, caused by acoustic waves varying the length and/or refractive index of the coils. The detector 40 uses a time division multiplexer (not shown) to look at the signal from individual coils separately. The coils are of the order of a hundred metres long, such that the time difference between the pulses f1 and f2 is of the order of microseconds as is the time difference between the interacting pulses to be detected. As it is phase change of electromagnetic radiation that is measured and the electromagnetic radiation is in or near the optical region then length changes of the order of nanometres can be measured. The flexible mandrel 20 is formed from an acrylic.

Figure 3A shows alternative constructions of acoustic sensors for use in embodiments of the present invention. These fibre optic sensors comprise a region of optical fibre 60 doped with, for example, erbium, to form a lasing volume and comprising Bragg gratings written on to this lasing volume, the Bragg gratings acting as the mirrors for the lasing volume. Two types of fibre laser geometries are shown. The first comprises the two Bragg gratings having merely a quarter wavelength change in phase separating them, this is called a DFB (Distributed Feed Back) fibre laser. The second comprises the two Bragg gratings at a distance from each other with the cavity therebetween, this is called a DBR (Distributed Bragg Reflector) fibre laser. The fibre optic lasers are pumped by an electromagnetic source 80 and the laser radiation generated is monitored. Acoustic waves 55 falling on the optical fibre cause changes

in the fibre length and possibly the refractive index, and thus changes in the Bragg grating pitch, which results in a shift in the laser wavelength generated.

Generally, the DFB fibre laser is considered to be optically more stable than the DBR device. Furthermore, it is currently being produced commercially so that the price of this device is expected to reduce significantly in the future.

In preferred embodiments, the doped optical fibre 60 and adjacent lengths of optical fibre 70 are coated with polyurethane. Acoustic waves 55 falling on the optical fibre set up vibrations in the polyurethane, this increases the sensitivity of the device to acoustic waves.

Figure 3B shows a musical instrument sound detection system comprising fibre laser acoustic sensors as shown in Figure 3A. In this system an electromagnetic source of radiation 80 transmits electromagnetic radiation into an optical fibre 90. The electromagnetic radiation is guided via a wavelength division multiplexing (WDM) coupler 85 to the fibre laser acoustic sensors 100, such as those disclosed in Figure 3A. Electromagnetic radiation generated by the optical fibre laser sensors propagates back through the WDM coupler and optical isolator 95 (included to prevent unwanted reflections returning to the sensors elements) prior to entering the input of a Mach-Zehnder Interferometer (MZI). The MZI geometry shown employs a path imbalance coil 120 and two acousto-optic modulators (AOM). The AOM's are set at 80.00MHz and 80.04MHz generating a difference frequency of 40KHz. In this system a wavelength division multiplexing unit 130 is used to separate the signals which are then sent to detectors 140.

The detectors of Figures 2B and 3B may be connected to a signal processor operable to relate these changes in phase or wavelength to the acoustic waves that produced them. In order to be able to monitor the acoustic waves picked up by individual sensors a pulsing system with time division multiplexing of the signals is used for the interferometric acoustic sensors or a wavelength division multiplexing system is used for the fibre laser sensors. If different sensors are used in the same system then the two multiplexing systems may be used together. In the embodiment shown, the fibre optic acoustic sensors are arranged in series, in alternative embodiments they may be arranged in parallel.

Figure 4 schematically shows a cross section of a solid bodied guitar having a fibre optic acoustic sensor 160 attached between the body 180 and the strings 150 of the instrument. The sensor detects the sound of the strings without affecting their movement. There exist a range of sensing means from vibration of the solid body to 'in-air' detection of the vibrating string. These different modes of detection can be accessed by altering the position (defined by h in figure 4) of the longitudinal axis of the sensor from the upper surface of the solid body. It should be noted that acoustic vibrations are different at different points on the soundboard (and the string) so that the positioning of the acoustic sensor (defined by d in figure 4) also affects the sound detected. A plurality of sensors can be used, with each placed at a different position so that different tonal qualities of the sound can be detected

The sound detection system of the present invention may be coupled via a signal processor to a recording system, such that the sound detected can be recorded; alternatively it may be connected to an amplification system enabling the detected sound to be amplified and broadcast via a loudspeaker.

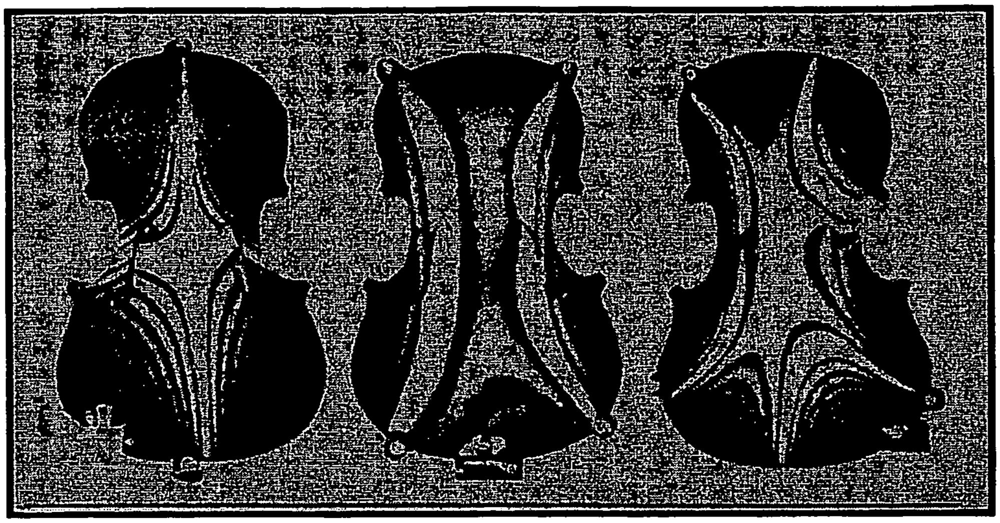


Figure 1

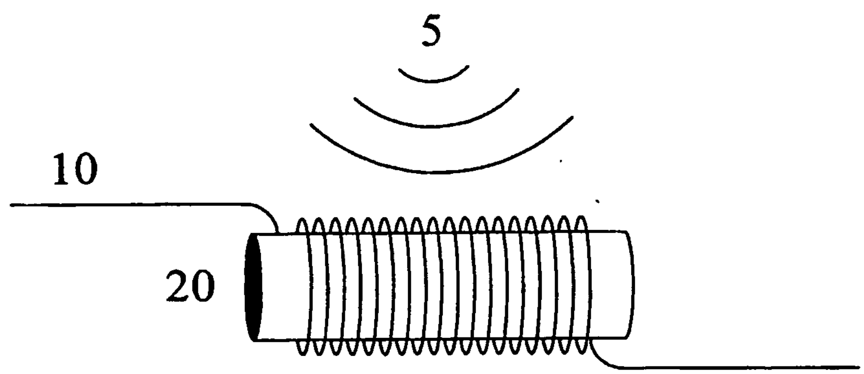


Figure 2A

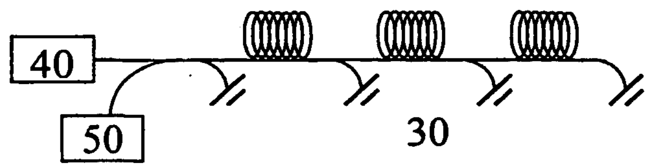


Figure 2B

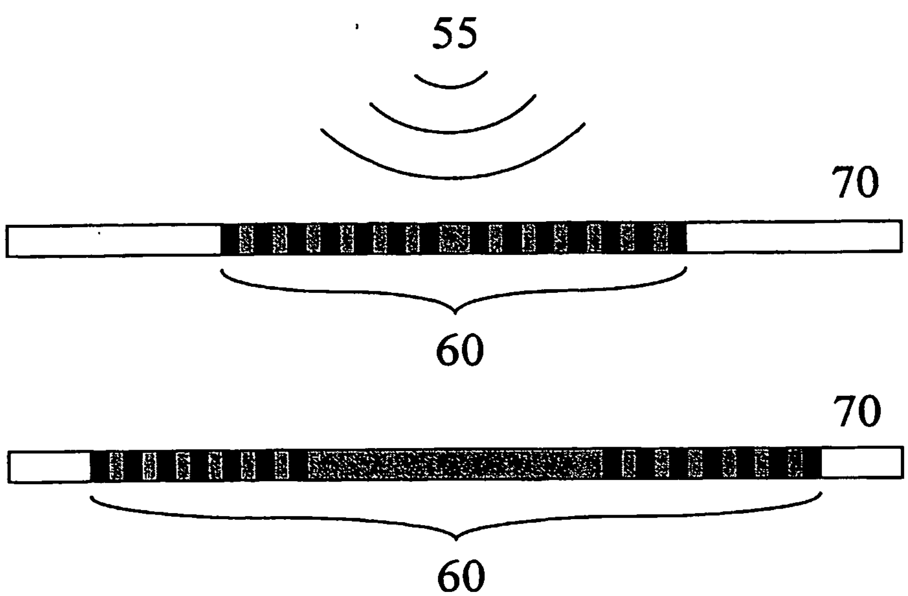
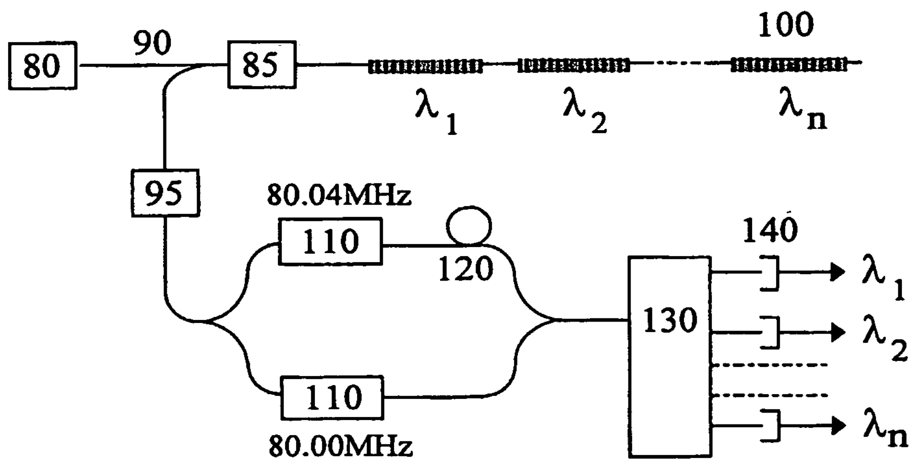


Figure 3A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90
85
100
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λ2
λn
95
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110
120
140
130
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Figure 3B

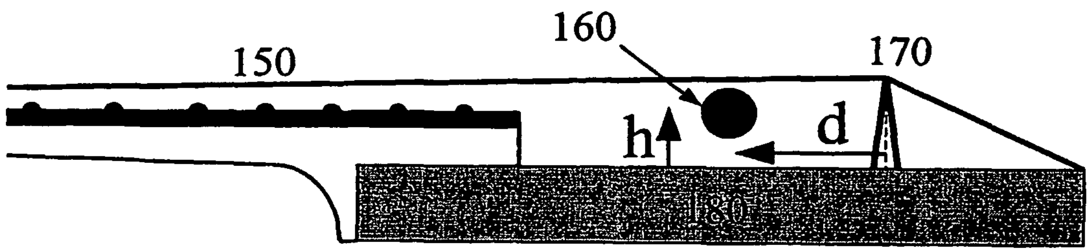

Figure 4